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ABSTRACT

Science Curriculum Improvement Study (SCIS) students in grades 4-6 were used to investigate ecological concept formation. Researcher-designed, multiple-choice and free-sort tasks were administered. Statistics utilized included analysis of variance, Spearman correlation, multiple regression, frequency distributions, and latent partition analysis. Findings show that: (1) grade and ability, not sex, influenced concept attainment and similarity of conceptual system to discipline structure; (2) sequence of concept attainment was not influenced by grade, ability, or sex; (3) concept attainment was promoted by a conceptual system similar to the discipline structure; (4) sixth-graders recognized life requirements, interactions via food, mineral, gas exchange, and community groups, but not attributes of higher-order concepts (producer, consumer, decomposer, environmental factors); (5) discipline experts, not students, related examples to higher-order concepts. Recommendations for grades K-6 curriculum are to promote conceptual systems similar to discipline structure, to base concept maps upon lower-order concepts or attributes, to eliminate higher-order concepts, and to emphasize interactions of plants, animals, decayers, non-living materials, feeding relationships, and life requirements. (Author/JN)

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THE FORMATION OF ECOLOGICAL CONCEPTS AND CONCEPTUAL SYSTEMS BY UPPER ELEMENTARY STUDENTS

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Because of concern for the deteriorating quality of the environment, a trend emerged in the early seventies to incorporate ecological concepts into the elementary curriculum. The Science Curriculum Improvement Study, SCIS, was a leader in the development of elementary environmental curricula (Karplus and others, 1974). Innovative features of the program included: a) the introduction of ecological concepts formerly confined to secondary curricula, and b) an emphasis upon the development of student conceptual systems which were similar to the discipline structure.

Lowell's Model of Through (1979) depicted knowledge as hierarchical with the base of the hierarchy consisting of lower-order classificatory concepts which were subsumed by higher-order classificatory concepts, relational concepts, and theoretical concepts. Generally, elementary students were considered capable of mastering lower-order classificatory concepts and concrete relational concepts. Concept studies with elementary students support this model. Research studies by Perry and Merkle (1976), Allen (1975), and Tamir (1981) indicated that elementary students could identify living and non-living components of the ecosystem, relate an organism to its habitat, and interpret feeding relationships depicted in food chains and webs. In contrast, elementary students possessed limited understanding of the particle nature of matter, state changes, chemical and physical changes, and energy transformations (Voelker, 1983). These studies suggest that elementary students' ability to conceptualize higher-order classificatory concepts and abstract relational concepts is questionable.

The learning theories of Bruner (1967), Gagne (1965), and Ausubel (1972) postulate that concepts are arranged in a definite pattern in an individual's

long-term memory or cognitive structure. To Bruner (1967), learning structure was learning how things were related, with the most efficient structure being the discipline structure. Perceived benefits of learning structure include increased understanding of the subject matter and enhanced subject matter retention (Shavelson, 1974). Conceptual themes and concept maps or diagrams are used to teach the structure of the discipline. Preece (1978) reported specific differences between the conceptual systems of unsophisticated learners, which were based upon small isolated groups of relational concepts, and those of sophisticated learners, which were based upon tightly organized hierarchies that were congruent with the discipline structure. Toews (1976) reported that upper elementary students' conceptual themes were more numerous and simpler than the themes used in the science program. These studies suggest that the appropriate conceptual system for a science program would differ with the age and sophistication of the learner. Because the discipline structure for the ecosystem is hierarchical, potential discrepancies exist between the conceptual system used in the SCIS program and the developmental stage of the learner.

Renner, Abraham, and Stafford (1978) cited the need to investigate the influence of key student characteristics, such as age, ability, and sex upon the development of specific concepts. The literature review revealed that older or more intelligent students reached higher levels of concept attainment, used more complex conceptual systems, and possessed a conceptual system similar to the discipline structure. The influence of sex on concept development was questionable but appeared to increase with age and to reflect differing societal expectations for male and female students. Because no major studies investigating the concept attainment of various groups completing the SCIS Life Science Program are reported in the literature, major

questions remain. Which student characteristics influenced the development of ecological concepts and conceptual systems? To what extent were ecological concepts mastered? To what extent did SCIS students develop a conceptual system of the ecosystem similar to the discipline structure? Does a student's conceptual system influence conceptual understanding of the ecosystem? Because the development of effective environmental curricula is dependent upon answers to these questions, the following study was conducted.

Statement of the Problem

The general purpose of the study was to provide descriptive information on the achievement of various groups of SCIS students including the level of ecological concept development, the type of conceptual system used by SCIS students and discipline experts to organize ecological concepts, and the influence of the conceptual system upon concept attainment. For statistical purposes, four major questions were established:

1. Is conceptual understanding of the ecosystem related to the grade level, ability level, or sex of the student?

2. Is the sequence of development of conceptual understanding of the ecosystem related to the grade level, ability level, or sex of the student?

3. Is the similarity of a student's conceptual system and the discipline structure related to the grade level, ability level, or sex of the student?

4. Is the similarity of a male or female student's conceptual system and the discipline structure a predictor of conceptual understanding of the ecosystem when the influence of grade level and ability level are removed?

Definition of Terms

Conceptual Understanding of the Ecosystem: the score received by the student on the Ecosystem Test.

Sequence of Development of Conceptual Understanding: the rank order of items on the Ecosystem Test from least to most difficult, with difficulty defined in terms of the percentage of students answering the items correctly.

Student's Conceptual System: the pattern used by an individual to sort the fifteen concepts in the Ecology Card Sort. It was operationally defined as the matrix of values obtained when the sort pattern was represented as entries of "1" or "0" in a 15 x 15 matrix with "1" representing grouped concepts and "0" ungrouped concepts.

Discipline Structure: the average of the patterns used by eight discipline experts (biologists, ecologists, science educators) to sort the components of the Ecology Card Sort. For descriptive purposes, it was defined as the pattern produced when the individual patterns were averaged and analyzed with the statistical procedure latent partition analysis (Harasyn and Precht, 1971). For data analysis, it was defined as the matrix obtained when the average pattern was represented as entries of "1" or "0" in a 15 x 15 matrix.

Similarity of Student's Conceptual System and Discipline Structure: the value calculated using the formula, $N_{ij}/\sqrt{N_i}\sqrt{N_j}$, for the Sorter Intersection Coefficient (Hart and Toews, 1980). N_{ij} represents the number of concept pairs common to the student's conceptual system and the discipline structure, N_i represents the number of concept pairs in the student's conceptual system, and N_j represents the number of concept pairs in the discipline structure.

Procedures

Sample

The population consisted of fourth, fifth, and sixth grade students enrolled in a southwestern Virginia school division who were given parental permission to participate. Since 1976, SCIS had been the adopted science program. The students were drawn from a total rural and small-town population of forty-five thousand people with the primary industries being agriculture, agribusiness, textiles, and furniture. From the fourteen elementary schools in the county, five were selected at random to participate in the study. A stratified sample of 288 subjects was selected which contained equal numbers of fourth, fifth and sixth grade students (n=96); equal numbers of students with below average, average, and above average ability (n=96); and equal numbers of males and females (n=144). The second grade score on the Otis-Lennon Mental Ability Test was used to determine the student's ability level (Otis and Lennon, 1969). The mean ability score was 80.6 for below average students, 100.1 for average students, and 120.2 for above average students.

Instruments

Research instruments were the Class Data Sheet, Demonstration Food Sort, Ecosystem Test, and Ecology Card Sort. All instruments were developed by the experimenter. A pilot study was conducted to develop instruments, establish reliability of the instruments, and develop procedures for administration. The Class Data Sheet was used to collect information on grade level, age, sex, and ability. The Food Sort, which consisted of a flannel board and ten flannel backed labels containing the name of a food, was used as a group demonstration of free-sort categorization procedures.

The Ecosystem Test assessed mastery of the concepts: producer, consumer, decomposer, environmental factors, community, ecosystem, food-mineral cycle, and oxygen-carbon dioxide cycle. Voelker's (1972) Model of Concept Development was used to construct forty-six test items which required students to select examples, definitions, critical attributes, and principles. Content validity was established by correlation with four representative elementary science programs (Barufaldi, 1981; Brandwein, 1980; Karplus, 1974; Rockcastle, 1980). The test had a Cronbach Alpha reliability of .826 as determined by the SPSS reliability subprogram (Hull and Nie, 1981).

The Ecology Card Sort consisted of an envelope containing eight paper clips and fifteen two by three inch cards on each of which a single concept was printed. The subjects used free-sort categorization procedures to sort the concepts into groups. Content validity was established by correlation with the key concepts of the discipline and examples given in the aforementioned elementary science programs. The reliability was established by computing the Pearson Product Moment Correlation ($r=.347$, $p \leq .001$) for student sort patterns on two separate administrations separated by a fourteen day period (Nie and others, 1975). The discipline structure was obtained by administering the sort to eight biologists, ecologists, and science educators and statistically averaging the results with latent partition analysis. The discipline structure contained five groups: (1) producer--bush, corn, oak; (2) consumer--beetle, grasshopper, prairie dog; (3) decomposer--bacteria, mold; (4) environmental factors--carbon dioxide, water; (5) community. The first four groups contained a higher-order classificatory concept (e.g. producer) and related examples (e.g. bush, corn, oak). The fifth group was composed of the supraordinate classificatory

community. The discipline experts had similar sort patterns (cohesiveness=.960) and exhibited little disagreement (ambiguity=.07) about the placement of concepts into groups.

Data Collection and Statistical Analysis

The research instruments were administered during the regularly scheduled science class period by the classroom teacher according to the following schedule: a) Directions for Ecosystem Test (five minutes); b) Completion of Ecosystem Test (thirty-five minutes); c) Break (five minutes); d) Demonstration Food Sort (10 minutes); e) Directions and Completion of Ecology Card Sort (15 minutes). The student's descriptive data and responses to the instruments were coded for keypunching and subsequent processing by the University of Virginia's Cyber 172 computer.

A 3 x 3 x 2 factorial analysis of variance design, blocked by grade level, ability level, and sex was used with major questions one and four. The dependent variables were the score on the Ecosystem Test (question one) and the Sorter Intersection Coefficient, SIC value (question four). The SPSS subprograms for analysis of variance and Scheffe's Multiple Range Test were used for the analysis (Nie and others, 1975). The computer programs SICVALU, INDMTRX, and MATRXIN were used to obtain the SIC value and prepare data for entry into the latent partition analysis program (Bishop, 1982 a, b, c). Descriptive data for major question four was obtained by latent partition analysis (Harasyn and Precht, 1971).

Spearman Rank Order Correlation was used to analyze data for the second major question (Nie and others, 1975). The dependent variable, difficulty level, was obtained from frequency distributions.

Step-wise multiple regression was used with major question four. The student variables of grade level and ability level were forced to enter the

regression first in order to accurately assess the ability of the SIC value to predict the score on the Ecosystem Test. Each successive step of the regression was calculated with the previous step removed (Nie and others, 1975).

A .05 level of significance was established as the criterion for acceptance or rejection of the null hypotheses associated with the four major questions.

Findings

Question One

A three-way analysis of variance design blocked by grade level, ability level, and sex was used to test four hypotheses:

1. There is no significant difference in the mean achievement scores of fourth, fifth, and sixth grade students on the Ecosystem Test.

2. There is no significant difference in the mean achievement scores of students with below average, average, and above average ability on the Ecosystem Test.

3. There is no significant difference in the mean achievement scores of male and female students on the Ecosystem Test.

4. There are no significant first- or second-order interactions of grade level, ability level, and sex as displayed by mean achievement scores on the Ecosystem Test.

The results of the analysis of variance are presented in Table I.

Insert Table I

The mean scores of fourth (22.58), fifth (24.92), and sixth (28.75) grade students differed significantly ($F=33.19$, $p \leq .001$). A significant difference was also found among the mean scores of students with below average (22.32), average (24.26), and above average (28.66) ability ($F=33.41$, $p \leq .001$). The mean achievement scores of male (25.49) and female (25.34) students were not significantly different ($F=.138$, $p \leq .711$). There were no significant first or second order interactions. Null hypotheses one and two were rejected; null hypotheses three and four were accepted. Additional analyses of various subtests e.g., producer, consumer, decomposer, and environmental factors also indicated a significant relationship for grade and ability level, but not for sex.

Question Two

Spearman's Coefficient of Rank Order Correlation was used to test three hypotheses:

5. The rank order of test questions on the Ecosystem Test by difficulty is not significantly different for fourth, fifth, and sixth grade students.

6. The rank order of test questions on the Ecosystem Test by difficulty is not significantly different for students with below average, average, and above average ability.

7. The rank order of test questions on the Ecosystem Test by difficulty is not significantly different for male and female students.

The Spearman Coefficients of Correlation (p) obtained in the analysis of data are presented in Table II. The sequence was equivalent for

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Insert Table II

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fourth, fifth, and sixth grade students; students with below average, average, and above average ability; and male and female students. Null hypotheses five, six, and seven were accepted.

The percentage of students responding correctly to an item increased with grade and ability level. Items were classified as very easy (.85-1.00), moderately easy (.60-.84), moderately hard (.35-.59), and very hard (.00-.34) in accord with the criteria established by Doran (1980). The descriptive data suggested that the following concepts were understood by sixty percent or more of the students in the designated grade level(s):

1. feeding relationships depicted in food webs (grades 4,5,6);
2. life requirements of plants and animals (grades 4,5,6);
3. rotting of dead plants and animals to minerals (grades 5,6);
4. interactions of plants (producers), animals (consumers), and decay organisms via the food-mineral cycle (grades 5, 6);
5. examples of the major components of the ecosystem (grade 6);
6. grouping of organisms into communities which interacted with the environment (grade 6).

Approximately fifty percent of the sixth grade students successfully answered questions involving the interaction of organisms via the oxygen-carbon dioxide cycle. Less than fifty percent of the sixth grade students successfully answered items involving definitions or critical attributes of the higher-order classificatory concepts. The response patterns for ability and grade level were similar. No difference in response patterns existed for male and female students. The response patterns could not be explained in terms of reading difficulty alone.

Question Three

A three-way analysis of variance design blocked by grade level, ability level, and sex was used to test four hypotheses:

8. There is no significant difference in the mean SIC value for fourth, fifth, and sixth grade students.

9. There is no significant difference in the mean SIC value for students with below average, average, and above average ability.

10. There is no significant difference in the mean SIC value for male and female students.

11. There are no significant first or second-order interactions of grade level, ability level, and sex as displayed by the mean SIC value.

Table III shows the results of the analysis of variance. The student

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Insert Table III

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characteristics of grade level ($F=18.23$, $p \leq .001$) and ability level ($F=10.48$, $p \leq .001$) did influence the similarity of a student's conceptual system to the discipline structure as revealed by the SIC value. The mean SIC value of sixth grade students (.595) was significantly higher than the mean SIC value of fourth graders (.512). The SIC values of students with above average ability (.588) and below average ability (.525) also differed significantly. Mean SIC values for male (.547) and female (.566) students were not significantly different ($F=2.70$, $p \leq .102$). There were no significant first or second order interactions. Null hypotheses eight and nine were rejected; null hypotheses ten and eleven were accepted.

Three identical groups were found in the student sort patterns: (1) bush, oak; (2) beetle, grasshopper, prairie dog; (3) bacteria, mold. Variations existed in the placement of the remaining concepts into two or

three groups. The grouping pattern for sixth grade students, which most closely resembled the discipline structure, contained two additional groups: (1) corn, water; and (2) carbon dioxide, community, consumer, decomposer, environmental factors, producer. In general, older or more intelligent students sorted the same concepts together with greater frequency (high cohesiveness value), but exhibited less agreement concerning the placement of concepts into groups (high ambiguity value).

Question Four

Step-wise multiple regression was used to test the following hypotheses:

12. The SIC value for a male student is not a significant predictor of the score on the Ecosystem Test when the influence of grade level and ability level are removed.

13. The SIC value for a female student is not a significant predictor of the score on the Ecosystem Test when the influence of grade level and ability level are removed.

The results of the regression analysis for male students are presented in Table IV. The multiple regression (R=.560) was significant at the .001 level. Each of the variables had a significant F-to-enter. Null hypothesis twelve was rejected. The variance explained by the SIC value (4.3%) was very small in comparison with the variance explained by ability and grade level (26.74%) or the unexplained variance (68.7%).

Insert Table IV

The results of the regression analysis for female students are presented in Table V. The multiple regression (R=.686) was significant at the .0001 level. Each variable had a significant F-to-enter. Null hypothesis thirteen

was rejected. Again, the SIC value accounted for a small amount of variance (4.4%) when compared with the grade and ability level (42.7%) and the unexplained variance (52.9%).

Interpretation and Discussion

The results of the study indicate that grade level and ability level, but not sex, significantly influence the development of ecological concepts by SCIS students. Both learning theories and concept development studies support the relationship of grade and ability level to concept attainment. The non-significant finding for sex is supported by the research of Clark (1971), Perry and Merkle (1976), and Hounshell and Liggett (1976) but conflicts with the findings of studies by Allen (1975), Perkes (1973), Bohl (1977), and Richmond and Morgan (1977) in which male students scored higher on ecological concepts. A possible explanation is that the activity-oriented nature of the SCIS Program reduced the differential backgrounds of male and female students which often result from sex stereotyping.

The findings also indicated that grade level, ability level, and sex did not influence the sequence of development of ecological concepts. The rank order of items by difficulty was similar to the sequence in the SCIS, and other elementary, science programs and to the sequence predicted by the literature review. However, concept mastery was not as great as anticipated. Mastery of life requirements, feeding relationships, and food-mineral cycle was expected in terms of the SCIS curriculum and was supported by the studies of Perry and Merkle (1976), Tamir (1981), and Allen (1975). That only fifty percent of students conceptualized the grouping of organisms into communities and interactions via the oxygen-carbon dioxide cycle was unexpected, for these concepts are emphasized in the fifth and sixth grade

SCIS units. A possible explanation is that the sixth grade students had not developed the formal thought processes necessary to understand gas movement or to utilize multiple levels of classification. Elementary programs vary in the inclusion of these concepts. For example, producers and consumers are related via the oxygen-carbon dioxide cycle in the Addison-Wesley program but not in the Heath or Concepts in Science programs. The inability of sixth grade students to articulate attributes of the higher-order classificatory concepts was also unexpected given the emphasis in the SCIS program. However, the results were supported by the literature which indicated that ability to select examples and principles preceded the ability to articulate the concept or to classify by group name (Goldman and Levine, 1963; Reichard, Schneider, & Rapaport, 1944; Voelker, 1972). A possible explanation is that the concept invention stage of the SCIS Learning Cycle was not adequately emphasized; therefore, students developed subverbal awareness of the concepts but could not articulate them. A second explanation is that the higher-order classificatory concepts, which are also included in the Heath and Addison-Wesley programs, are too difficult. The Concepts in Science program does not use the terms but refers to the groups by their attributes e.g., food maker. Additional study on the appropriateness of these concepts for the elementary learner is needed.

The finding that grade and ability level, but not sex, influenced the type of conceptual system was expected and substantiated by grouping studies conducted by Goldman and Levine (1973) and Reichard, Schneider, and Rapaport (1944). Differences between the conceptual systems of elementary students and discipline experts were congruent with Preece's (1978) findings. Descriptive data from the Ecology Card Sort supported data from the Ecosystem Test for elementary students did not utilize the classificatory concepts as subsummers. Students did place plants, animals, foods, and decayers together,

suggesting that some classification system was utilized. Given the numerous grouping activities in the SCIS program, the results were unexpected. Perhaps teachers were: a) unaware of the importance of the activities and did not engage students in sufficient discussion of the reasons for placement of an organism into a given category, or b) the task was inherently too difficult when structure (e.g., the pyramid) was not provided.

The significant influence of a conceptual system similar to the discipline structure on concept attainment supports the tennents of learning theorists and the emphasis placed upon structure in the SCIS Program. The differences between student and expert sort patterns suggest intermediate stages which may be beneficial as a transition to the discipline structure.

Recommendations

Based upon the findings, the following recommendations are made:

1. The activity-oriented nature of the SCIS Program should be continued for it was successful in eliminating differentiated concept development by males and females.

2. The SCIS materials which developed life requirements, feeding relationships, and food-mineral cycle were effective and should be retained. Use of similar materials in other elementary science programs should be encouraged.

3. The SCIS materials which developed the higher-order classificatory concepts and the oxygen-carbon dioxide cycle should undergo additional testing. Further studies are needed to determine if the limited concept development was a function of the population or typical of all students completing the SCIS program.

4. The SCIS program should continue to emphasize the development of a conceptual system similar to the discipline structure; however, the

activities should be revised to include intermediate stages in which students group examples under lower-order concepts (plants, animals, etc.) or by attribute (non-living, food-maker, etc.). Additional studies should be conducted to discover the stages preceding attainment of the discipline structure for the ecosystem. Other elementary science programs should be encouraged to include activities which promote development of the discipline structure.

5. Additional studies should be conducted to determine the success of other elementary science programs in developing the higher-order classificatory concepts: producer, consumer, decomposer, environmental factors, community, ecosystem, and the oxygen-carbon dioxide cycle.

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Table I

Results of the Three-Way Analysis of Variance of the Mean Achievement Scores on the Ecosystem Test

Source of Variation	Sum of Squares	df	Mean Square	F-ratio	Significance of F
MAIN EFFECTS	3437.67	5	687.94	26.67	.001*
Grade Level (V6)	1712.44	2	856.22	33.19	.001*
Ability Level (V4)	1723.67	2	861.84	33.41	.001*
Sex (V5)	3.56	1	3.56	.138	.711
TWO-WAY INTERACTIONS	250.65	8	31.33	1.22	.290
Grade (V6) X Ability (V4)	151.58	4	37.89	1.47	.212
Grade (V6) X Sex (V5)	96.78	2	48.39	1.88	.155
Ability (V4) X Sex (V5)	2.30	2	1.15	.05	.956
THREE WAY INTERACTIONS					
Grade (V6) X Ability (V4) X Sex (V5)	61.12	4	15.28	.59	.668
EXPLAINED	3751.44	17	220.67	8.55	.001*
RESIDUAL	6964.88	270	25.79		
TOTAL	10716.32	287	37.34		

Table II

Spearman Rank Correlation Coefficients for the Rank Order of Test Items on the Ecosystem Test By Various Subpopulations

Variables Correlated	Spearman's Coefficient of Rank Correlation (p)	Significance
Grade 4 with Grade 5	.908	.001*
Grade 4 with Grade 6	.876	.001*
Grade 5 with Grade 6	.916	.001*
Below Average Ability with Average Ability	.932	.001*
Below Average Ability with Above Average Ability	.879	.001*
Average Ability with Above Average Ability	.920	.001*
Male with Female	.952	.001*

Table III

Results of the Three-Way Analysis of Variance of the Mean Sorter Intersection Coefficient

Source of Variation	Sum of Squares	df	Mean Square	F-ratio	Significance of F
MAIN EFFECTS	.554	5	.111	11.942	.001*
Grade Level (V6)	.338	2	.169	18.227	.001*
Ability Level (V4)	.195	2	.097	10.484	.001*
Sex (V5)	.025	1	.025	2.695	.102
TWO-WAY INTERACTIONS	.050	8	.006	.680	.709
Grade (V6) X Ability (V4)	.017	4	.004	.462	.764
Grade (V6) X Sex (V5)	.020	2	.010	1.099	.335
Ability (V4) X Sex (V5)	.013	2	.006	.685	.505
THREE WAY INTERACTIONS					
Grade (V6) X Ability (V4) X Sex (V5)	.027	4	.007	.724	.576
EXPLAINED	.631	17	.037	4.003	.001*
RESIDUAL	2.477	267	.009		
TOTAL	3.108	284	.011		

Table IV

Multiple Regression Analysis Relating Male Student's Grade Level, Ability Level, and Sorter Intersection Coefficient to the Score on the Ecosystem Test

Step	Variance	F-to-Enter	Significance	Multiple R	R^2	Overall F	Significance
1	Grade Level	16.09	.000	.359	.129	21.34	.0001
2	Ability Level	19.75	.000	.517	.267		
3	Sorter Intersection Coefficient	9.39	.003	.560	.313		

Table V

Multiple Regression Analysis Relating Female Student's Grade Level, Ability Level, and Sorter Intersection Coefficient to the Score on the Ecosystem Test

Step	Variable	F-to-Enter	Significance	Multiple R	R^2	Overall F	Significance
1	Grade Level	40.36	.000	.457	.207	41.57	.0001
2	Ability Level	49.76	.000	.654	.427		
3	Sorter Intersection Coefficient	11.58	.001	.686	.471		